than by the appearance of positive energy areas. The graph strikingly portrays this by the change of the slope of the tephigram and depegram. However, if with the approach of a new air mass no positive energy appears, it seems to indicate that there will be no violent thunderstorms in the neighborhood of the station itself.

(5) In some cases we have indicated positive and negative areas with reference to a unit mass of air taken at some other altitude than at the surface. In some cases, where there has been no positive area shown with reference to the surface, there is a positive area with reference to a higher point. Sometimes the positive area increases, sometimes decreases. In general, it may be stated that in the case of the approach and passage of a different air mass (frontal disturbance) the positive area increases, or the negative decreases, on succeeding graphs, while at the same time on any one graph the positive area seems to increase as the reference level of energy available is shifted upward. While it is true also of the convection type that succeeding graphs will show a gradual increase of positive area, the positive area on a single graph appears to decrease as the starting or reference point is moved upward. Theoretically, the total energy present in a certain layer could be found by adding the energy at each level, that is a more or less graphical integration of the positive and negative areas.

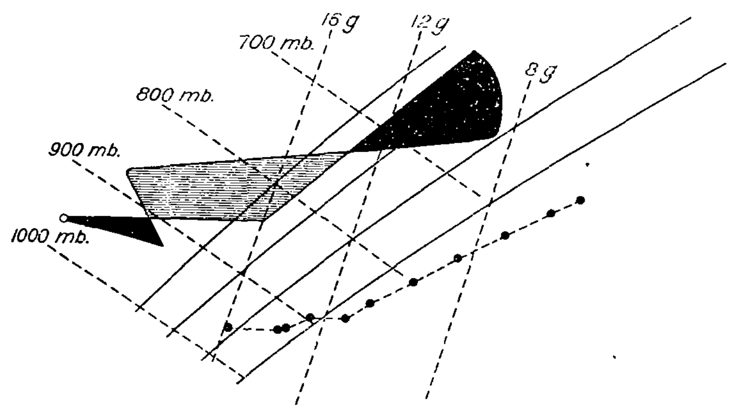

FIGURE 46.—Tephigram, Drexel, Nebr., August 21, 1918, 8:49 a. m.

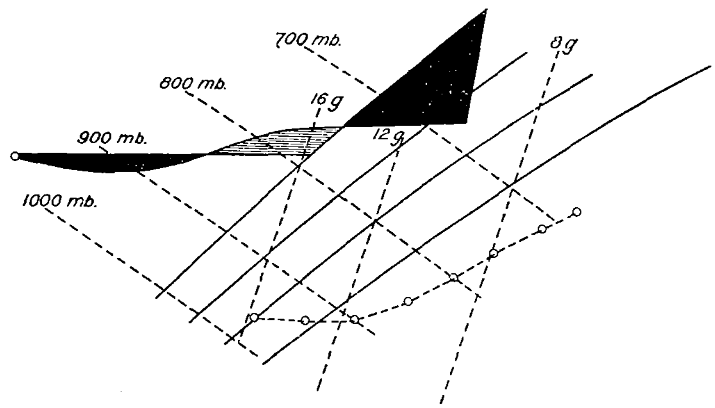

FIGURE 47.—Tephigram, Drexel, Nebr., August 21, 1918, 3:55 p. m.

Much can be written and said on the subject of tephigrams. Actually little practical use has been made, at least in America, up to the present time. This paper falls far short of any real comprehensive study of the subject, but it is hoped that enough has been shown to indicate the practical value of tephigrams as an aid in forecasting.

551.48 (794)

SOURCES OF LOCAL WATER SUPPLY [1]

By A. SONDERLEGGER, consulting engineer, Los Angeles, Calif.

It is a matter of general comment among the population of southern California that of late years we have passed through a period of drought. We have had one dry year after another; in fact, since the great floods of 1914 and 1916, we have had only three years of abnormal rainfall, while the other 10 years have been dry. Yet, we keep on pumping cheerfully from seemingly unlimited underground sources and nobody appears to worry very much except the superintendent of the water works.

The assertion is sometimes advanced that there are mysterious underground streams, or rivers, which convey water from the Mojave Desert to the Coastal Plain, or from as far distant sources as the Colorado River. There are no indications, or facts, in support of any such contentions. The mountain ranges which separate us from the desert are plutonic in origin. They are many miles in thickness and there are no passages or cavities to permit either a flow or a percolation of water across them.

Rainfall.—The water supply of any region in southern California depends entirely upon the rain falling on its contributory watershed and a study of rainfall phenomena will, therefore, disclose the basic factors affecting our water supply.

Rainstorms.—The major storms which drift from the Pacific Ocean over southern and central California are the result of areas of low barometer, usually moving from northwest to southeast. These storms are the most frequent bearers of our rainfall. They are general over the whole region and, as a rule, of fairly uniform relative intensity. The records of seasonal precipitation of any station thus are an index for a broad area.

Effect of altitude on rainfall.—The moisture-laden storm winds strike the coast from the southeast, south, and southwest. On encountering the mountains along the coast and in the interior they are forced to rise to higher altitudes, where they are cooled and precipitate a larger portion of their moisture. Thus with increasing altitude we find correspondingly larger precipitation up to about 6,000 feet, above which there is a slight decrease. This process of absorption of moisture is so effective that after passing the succession of ranges which parallel the coast there is little moisture left beyond the High Sierras, and the country to the east thereof is naturally barren. This phenomenon is illustrated on Plate 1, which represents a profile transverse to the major axis of the State, from the coast of San Luis Obispo easterly across the Santa Lucia Range to the San Joaquin Valley and thence over the High Sierras to Owens Valley and Death Valley. This is also illustrated on the same plate by a profile from the coast at Long Beach across the southern Coastal Plain and San Gabriel Valley, passing Mount Wilson of the Sierra Madre Range and on down to Palmdale in the Mojave Desert.

Rainfall cycles.—The rainfall of southern California is characterized by extreme irregularity not only from day to day or month to month of a rainy season, but also

[1] A collection of papers presented before the school of citizenship and public administration, University of Southern California, June 17-21, 1929.

from year to year. Yet, while there is an apparent irregularity of seasonal rainfall, it has nevertheless been established that within broad limits the fluctuations over long periods of years follow fairly well-defined laws, it being apparent that there are periods of wet years followed by dry periods. The duration of a complete cycle, consisting of a wet and a dry period, is 20 to 24 years, 10 to 12 years in which the average rainfall is above normal, followed by a like period in which it falls below normal.

This phenomenon naturally affects the water supply of the country to the extent that the fundamental problem with which the water-supply engineer is confronted is that of regulating an erratic supply.

Over long periods of years the consumption of water, through plant growth, corresponds to the average rain.

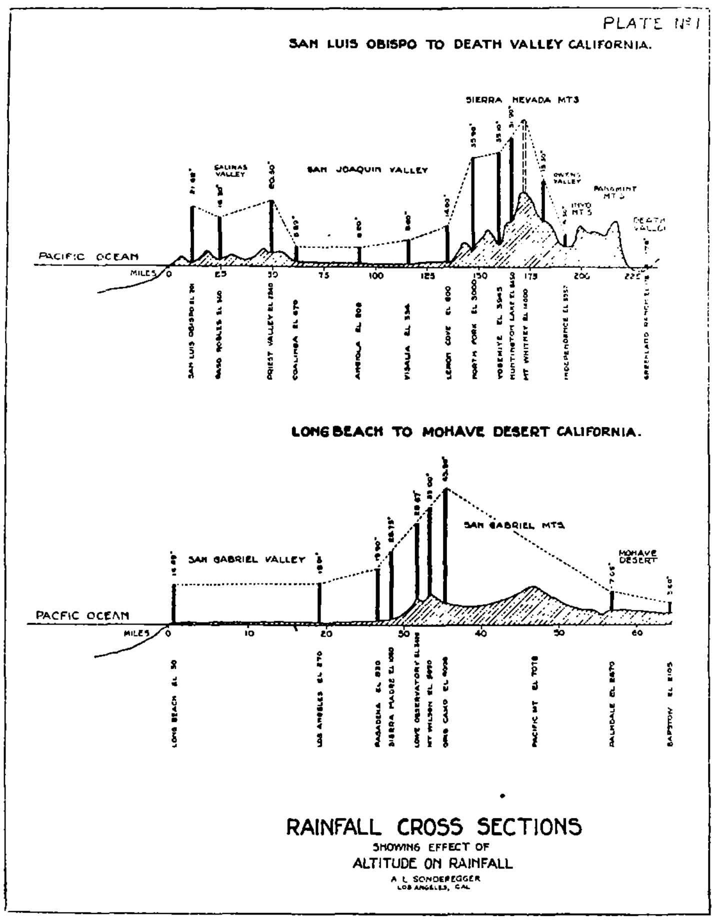

PLATE I.—Rainfall cross sections

During a series of wet years, with precipitation above normal, there will therefore be an accumulation of the surplus water reflected in heavier and deeper saturation of soils, larger stream flow, and rising ground-water levels. An occasional dry year in a wet period will only temporarily check the increase. On the other hand, a dry period will cause the gradual depletion of the water supply. This phenomenon is illustrated in Plate 2, Figures 1 and 2, which graphically show the seasonal rainfall at Los Angeles and the run-off of the San Gabriel River at Azusa for the years 1871 to 1924.

Figure 3 of the same plate shows the mass diagram, sometimes called "residual mass curve," of the rainfall for Los Angeles, platted so as to show the accumulative effect of the departure from the normal rainfall for the 53-year term. A rising line indicates a rainfall for a season above normal and a falling line a shortage. The general downward slope of the dash-and-dotted line denotes shortage over a period of years and consequently a gradual draft on the accumulated water supply, while ascent of the dash-and-dotted line indicates gradual storage of the surplus.

The mass curve then represents what would be the fluctuation of the water level in a tank exposed to the rainfall, from which annually the average amount of precipitation for the 53-year term, namely 15.01 inches, is extracted.

A similar illustration is presented in Figure 4 relating to the seasonal run-off of the San Gabriel River. The mass curve here presents again the fluctuation of the water surface of a reservoir in which the entire run-off would be impounded, with annual abstractions equivalent to the mean recharge for the 53-year term, namely, 135,800 acre-feet. It should be noted that the seasonal fluctuations of stream flow are much more erratic than those of rainfall. The periods of depletion and accumulation are clearly indicated as follows:

	1871–83, dry	1883–93, wet	1893–1904, dry	1904–16, wet	1916–24, dry
Average seasonal rainfall at Los Angeles..................inches..	13.83	20.32	11.25	16.90	12.47
Average seasonal runoff, San Gabriel River..............acre-feet..	97,258	224,470	52,427	187,492	120,162
53-year mean San Gabriel River, (135,800 acre-feet 100 per cent) ....per cent..	72	165	39	138	89

The run-off or water supply produced by the San Gabriel River in the driest period of record, 1893–1904, was only 28 per cent of the succeeding wet period. For these two periods, stream gagings exist for a sufficient number of years to make the results reliable. In order to equalize a water supply like that of the period from 1883 to 1904 to an average of 135,800 acre-feet per annum, storage capacity of nearly 1,000,000 acre-feet would have to be available, or about four times the capacity of the proposed San Gabriel Reservoir.

Figure 5, Plate 2, shows the fluctuations of a well at Baldwin Park in San Gabriel Valley for each year. The well responds to the variations in stream flow and rainfall. The ground-water basin of the San Gabriel Valley is therefore comparable to the tank above mentioned, and as a matter of fact operates as such. During a wet period this basin gradually fills with seepage water, both from the stream beds which traverse the valley and from direct percolation of rainfall, so that the water levels in wells keep on rising until this tide turns and the dry period sets in. Inasmuch as it is the function of a reservoir to be drawn down during dry years and to be replenished in wet ones, the lowering of the water table, as a result of years of drought, does not indicate or prove that the basin is overdrawn. The criterion of an overdraft is the nonreturn to original levels at the end of a wet period.

The diagrams of Plate 2 show the cyclic fluctuations as determined by observations of rainfall, stream-flow and ground-water levels. In southern California the water crop of dry periods is supplemented by cyclic underground storage. Dry years are particularly critical for the water users relying upon surface flow. The water supply must be gaged by the dry years' crop, and storage is required to regulate the excess flow of wet years. The development of a country based upon the supply of wet periods will sooner or later lead to economic disaster. The present status of the science of astronomy and the related science of meteorology does not permit of periodical weather forecasts. Predictions as to our future water supply therefore must be based entirely upon records of past performance. Under such conditions, the records of the driest period available, combined with the possibilities of cyclic storage, must be taken into consideration in estimating the available supply, particularly where domestic supply is concerned.

Disposal of rainfall.—Generally speaking, a portion of the rain falling on an area will seep into the ground at the point where it falls; another portion may flow for a distance on the surface or collect into drainage channels, there to seep away unless the storm be heavy enough to produce a run-off on the surface beyond the limits of the watershed, or even as far as tidewater. This "surface run-off," which takes place during a storm or for a few days following, is also termed "storm run-off."

The rain water which seeps into the ground saturates the soil to various depths, depending upon the magnitude of the storm. This seepage is, in turn, subject first to evaporation from the surface of the ground; second, to absorption by plant life; and, third, to deep percolation beyond the roots of plant life and beyond the limits of capillary action, depending upon soil formation and moisture conditions. Deep percolation may subsequently drain into gullies and creeks and thus form the normal flow of a stream which occurs between storms and with perennial streams also during the summer. The normal flow of a stream is therefore a seepage run-off, seeping into the ground first and thence draining therefrom.

The evaporation and transpiration losses are generally called the "consumptive use," which is essentially a function of the character and type of soil and the soil cover.

Rainfall is therefore disposed of as "consumptive use," "seepage run-off," and "storm run-off."

This disposal of rain water takes place on the valley floor as well as in the mountains, and both types of watersheds share in the production of our water supply.

The relative effect of rainstorms of various intensities leads to the conclusion that the largest contributions to our water supply are produced by storms of great intensity, which last over several days and produce valley rains of 8 to 12 inches for the storm. Such storms produce a large storm run-off from our mountains. On the other hand, in the valley they are the cause of the deep percolation which recharges the ground-water basins. A study of the effect of individual storms on stream flow and on the fluctuations of the ground-water table, will be found to be very instructive. As a rule, a wet winter will produce one storm of outstanding intensity, which is responsible for the greater portion of the water crop of the season.

Mountain run-off.—On a mountain watershed with residual soil cover seepage water may strike bedrock at a depth of 1 to 12 feet or more, there to be diverted downhill (see figs. 3 and 4 of plate 3). On its downhill course this percolating water has to run the gantlet of absorption by the roots of trees, brush, and herbs which may have penetrated fissues to depths of 20 to 30 feet. Abstraction therefore is extremely active until the percolating water reaches the stream bed. Despite this continued tapping, however, seepage run-off is produced in dry years, although this may, in part, be due to overyear storage and partly to absorption in talus slides, which, owing to their unstable and porous formation, readily admit the rain water.

The run-off of a mountain watershed is, as a rule, measured at the mouth of canyons and includes both the seepage or normal run-off and the storm run-off. It is the run-off that becomes available for water supply. Measurements of flow on the major streams are made by the United States Geological Survey and the results published in its water-supply papers. The run-off figures of the San Gabriel River used in the preparation of Figures 2 and 4 of Plate 2 were obtained from the water-supply papers of the United States Geological Survey.

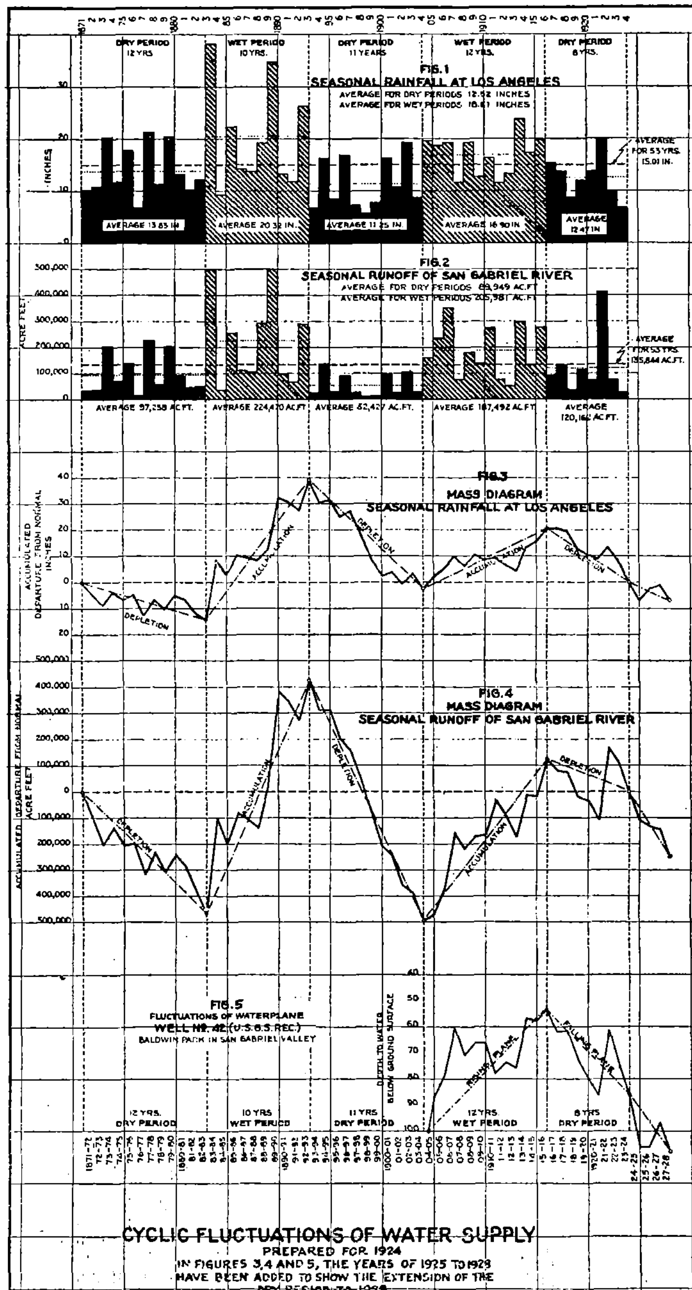

PLATE II.—Seasonal rainfall, Los Angeles, run-off of San Gabriel River, etc., as shown

The consumptive use of a mountain watershed for a 12-month season is obtained from the equation—

Consumptive use = seasonal rainfall minus run-off

A study of the daily discharge of a stream and its hydrograph will readily permit the segregation into seepage and storm run-off, since the latter is characterized by the violent and erratic departures from the more or less uniform normal flow.

For the mountain watersheds it has been found that the consumptive use of the brush or timber cover varies from

20 to 30 inches, and that this is, roughly speaking, two-thirds of the rainfall or total water supply. Of the remaining one-third, by far the larger portion is normal or seepage run-off and only a small part is storm run-off, except in years of heavy floods. The San Gabriel River, with a water shed of 222 square miles above Azusa, has an average seasonal run-off at that point of 135,800 acre-feet, or 600 acre-feet per square mile, equivalent to a depth of water spread over the water shed of 11.3 inches. The average rainfall on this watershed may be estimated at 31 to 36 inches, or about three times the average run-

PLATE Nº 3

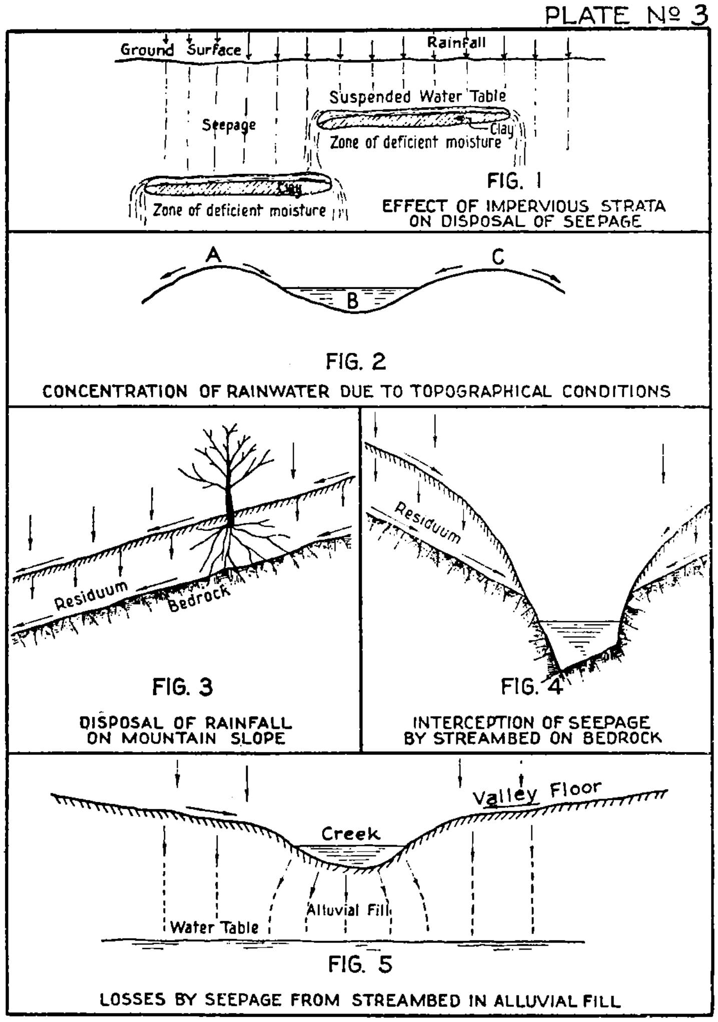

PLATE III.—Losses by seepage

off. For smaller watersheds and lower altitudes, the consumptive use is a still larger percentage of the rainfall and the run-off correspondingly smaller.

The fluctuations of run-off of individual years are even more erratic than the periodical fluctuations. The minimum seasonal run-off of the San Gabriel River occurred in 1898–99 with 9,630 acre-feet, equivalent to a depth of water over the whole watershed of less than 1 inch, and the maximum in the season of 1921–22, with 410,000 acre-feet.

Water supply from rainfall on the valley floor.—Seepage water penetrating intermittently below the limits of evapo-transpiration activity must ultimately cause the wetting to field capacity (or water capacity), either of the entire formation overlying the water table or of well-defined ducts reaching from the surface to the water table. If there is additional seepage from above, there must be a corresponding addition to the water table.

The alluvial deposits of which the fill of our valleys is made up are essentially heterogeneous in formation, consisting of irregular bodies of sand, gravel, and clay, so that the percolating fluid will naturally find lines of least resistance, to the effect that a uniform saturation over large areas and to great depths, is not likely to occur, but rather the formation of more or less defined ducts.

At points where percolating water strikes an impervious stratum, downward movement is interrupted and a suspended water table formed. Gradually lateral percolation is then established and a circuitous route for the percolating fluid is formed until another pervious deposit again permits of more or less vertical movement. Whenever a suspended water table has been formed the drainage from same will cover the edges of the impervious stratum and is likely to collect into trickling streams, as illustrated in Figure 1, Plate 3. These conclusions are supported by the fact that during the process of excavating shafts in alluvial fills it is quite common to strike dry materials alternating with moist materials and occasional streams of water. Inasmuch as alluvial deposits almost invariably show an alternation of pervious and impervious strata, the phenomenon indicated in Figure 1 is probably the one most commonly encountered. Under such conditions only a portion of the alluvial mass between the surface and the ground-water table will be saturated.

The recharge of the ground water may be hastened or delayed by impervious strata. Large clay bodies may not only cause a regulation of an irregular water supply, but they may also provide storage of a magnitude not appreciated because not readily traced.

Absorption is favored by the wedging action of roots, and especially by decayed roots, the latter having a tendency to drain a saturated mass along defined canals.

The intensity and effect of rainstorms is magnified by the irregularities of topography, whether they are the gentle undulations which occur on an apparently true plane, or hog wallows and hummocky undulations as shown in Figure 2, Plate 3. It is apparent that some of the rain falling on points A and C will flow on the surface to the depression B. A 3-inch rain may produce at B a depth of water of as much as 6 inches and a seepage greatly in excess of that at points A and C. This concentration of rain water, therefore, induces a corresponding concentration of seepage and may be responsible, in part, for deep penetration when the seasonal rainfall uniformly absorbed is not sufficient to satisfy the moisture deficiency and evapo-transpiration losses over large areas.

It is therefore concluded that the irregularities of topography, the heterogeneous character of alluvial soils, and the actions of roots all tend to concentrate percolation along lines of least resistance and that a uniform wetting of the soil over large areas, even to the depth of the root zone, is not likely to occur, with the ultimate result that larger portions of the valley rains reach the water table than is commonly assumed.

The quantity of the water supply resulting from rainfall on the valley floor is not readily ascertained and for this reason has in the past often been underestimated. The author has made extensive studies of this phenomenon, and his conclusions have been confirmed by the investigations of the engineers of the United States Department of Agriculture and State department of engineering.

In the San Bernardino Valley, above the lower Santa Anna Canyon, it has been determined that in certain years as much as 40 per cent of the total water-crop tributary to that valley is from rainfall on the valley floor, and that the contributions from this source exceed 200 acre-feet per square mile.

It goes without further explanation that the gentle rains and light storms of dry years do not produce deep penetration to any extent. It is the rainfall of normal, and particularly of wet years with their heavy storms that causes a substantial recharge of ground-water basins, which can be observed in the response of the water levels in wells. Where clay strata are extensive, this response is lagging, but nevertheless ascertainable. The average proportion of recoverable voids in alluvial materials is about 15 per cent; a rise of the water table by 1 foot over an area of 1 square mile would indicate a recharge of 96 acre-feet, equivalent to a depth of 1.8 surface inches of water.

Ground-water basins.—Even the casual observer will notice that Southern California is dotted with thousands of wells, operated by pumping plants. Probably 75 per cent of the water supply of this country is derived from underground sources. The drilling of great numbers of wells has disclosed that the principal valleys, from the San Luis Rey River northerly to the Sierra Madre Mountains, are underlain by deep basins filled with alluvial materials. Having been laid down by flowing streams, these deposits are arranged irregularly, with kidneys of clay interlaced with lenses of gravel or sand. The latter are the waterbearing gravels, which under favorable conditions may carry as much as one-third of voids, or interstices, which are filled with water, this water, in turn, being subject to abstraction by means of wells and pumps. The valleys, or basins, are shown on Plate 4.

The entire San Fernando Valley is underlain by such a basin, as is the San Gabriel Valley, the Coastal Plain from Santa Monica down to Newport, the San Bernardino Valley, San Jacinto Valley, etc. The storage capacity of these basins is so enormous that the capacity of surface reservoirs, even of the size of the San Gabriel Canyon Reservoir, is but a fraction thereof. The recharge of these basins is effected by seepage from streams which cross the valleys and from rain water seeping into the ground of the valley floor and beyond the roots of plant life, ultimately to reach the water table. The ground water, sometimes called the "underflow," percolates as a rule in the general direction of the surface stream. The rate of percolation is generally slow, ranging from 1 to 3 or 4 miles per year. Unless intercepted by barriers, the underflow will in its natural course reach the ocean underground.

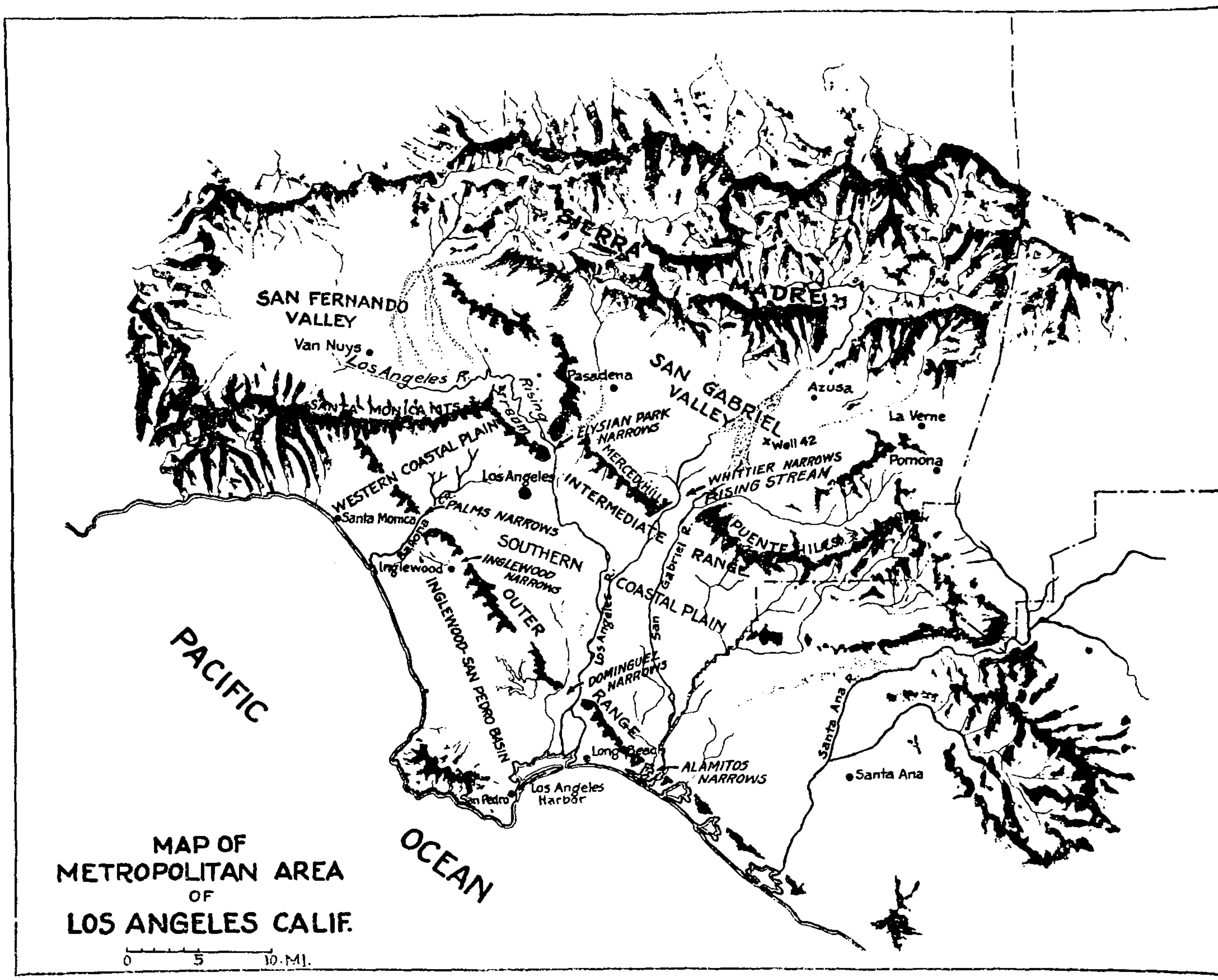

PLATE IV.—Topography of Los Angeles region

A characteristic of most of these basins is the occurrence of underground barriers (dikes) or of lateral constrictions, or both, which interrupt the percolation of the ground-water streams. Taking, for example, the San Fernando Valley, at Van Nuys the valley has a width of 8 miles and a depth to bedrock of 1,000 feet or more. At its outlet the valley is constricted from Burbank to Elysian Park by the approach from either side of the hill formation, narrowing the valley down to a width of three-fourths mile. This is the Elysian Park "narrows." There is, furthermore, an underground sandstone barrier which crosses the narrows at a depth of less than 200 feet below the surface. The combined effect of lateral constriction and barrier is to force the ground water to the surface and to form the rising stream of the Los Angeles River. This river begins as a small stream in the vicinity of Van Nuys and gradually increases on its course toward the Narrows to a flow of 40 to 50 second-feet, even in the summer months of a dry period. The Los Angeles River is therefore strictly a ground-water stream (except for its flood flow). In order to prevent pollution, the river is now drained by infiltration pipe lines, from whence it is conveyed to the city.

San Gabriel Valley extends from Pasadena to San Dimas, a distance of some 20 miles, and has a depth of alluvial fill of over 1,000 feet. At the Whittier Narrows the valley is constricted to a width of about 2 miles. The depth of fill at this point is about 480 feet. The effect of the "narrows" is a stream of rising water, beginning about at the Foothill Boulevard with a small stream and increasing, as the Mission Street Bridge is approached, to a river carrying 60 to 120 second-feet. This supply is diverted in a number of irrigation ditches.

The many narrows constricting our valleys or basins are indicated on Plate 4.

In the ground-water basins water will remain pure and potable for indefinite periods and is available for abstraction over long periods as it percolates from the mountains to the sea.

These ground-water basins present a natural and practical solution for the regulation of the otherwise erratic water supply of southern California, making it possible to store water from a wet period into a dry period; in other words, permitting of a cyclic regulation of water supply. For this reason they are the fundamental physical factor which made possible the development of this country.

Too much emphasis can not be placed on the economic importance of the deep gravel beds which underlie our valleys. The layman is inclined to lay stress on surface storage, believing that the water problem can be solved by the construction of surface reservoirs. The proper function of our flood control and conservation reservoirs is that of detaining floods. From such temporary storage the flood waters may conveniently be carried on to the gravel deposits below the mouths of canyons and there caused to sink into the ground, to become a portion of the ground water underlying our valleys. This method of conservation is also known as the spreading of flood waters and is now practiced on practically all rivers and streams of southern California.

AGRICULTURAL METEOROLOGY AND RAISING THE AGRICULTURAL PRODUCTIVITY

551.5 : 633

By Prof. A. KAÏGORODOFF

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1. The main work of contemporary agricultural meteorology consists at the present almost exclusively in parallel observations on the growth of some crops and the influence on them of meteorological factors.

2. The object of these observations, started in Russia in 1906 and in America in 1915–16, is the fixation of the "critical periods" in the growth of plants, in which they are most sensitive to excess and deficiency of heat and humidity, and the "correlational interdependence" between the harvest and the combination of the heat and humidity in the several intervals of the vegetative period.

3. This interdependence is of a rather vague character. It varies with the different climatic conditions for one and the same crop and shows a tendency of adapting itself passively to the climate.

The method applied in these researches is a passive observing one.

4. The meteorological observations, based on the contemporary international agreements, have but a limited value in the comparison of climates on broad scales, and their importance for practical agronomy is very small.

5. As a counterpoise to the foregoing and in addition to it, an experimental method is proposed to be applied at special microclimatic stations, observatories, and biometeorological laboratories.

6. The data on microclimate, or rather on bioclimate, are to be gathered by means of observations made with special instruments more exact and more sensitive than the ordinary ones, in the lowest strata of the atmosphere, 0 to 15 meters, having as their object the fixation of the movement and the limits of fluctuations of those meteorological factors most important for the life of the plants, which can directly bring to light the characteristics of the local climate.

7. The actinometric sections of the observatories, possessing exact physical instruments, mainly photo-actinometric, are to start a detailed study of solar energy, direct and dispersed, in the spectrum as a whole and also in its different regions, taking into account the local conditions of the solar climate.

8. Hand in hand with this the laboratories (biometeorological sections of the observatories) are to conduct, systematically and in detail, isolated vegetation experiments, using natural and artificial sources of light and an assortment of photophilters, the influence of light, direct and dispersed in the spectrum as a whole, and also in its different regions, on the development and chemism of plants.

9. As data on microclimate are gathered, the different elements should be in the limits fixed by experience for given regions, and introduced into the vegetation experiments as new variables, enabling thereby the calculation of the influence of divers factors of the bioclimate on the growth of different crops.

10. The totality of gathered facts will enable us to fix, with the aid of specialists—chemists, physiologists-botanists, selectioneers, etc.—the climatic "formulary" of the plant, depending on the natural conditions of the region, and thus to tie together the vegetable world with climatic conditions by a causal and uniform nexus.

11. The struggle against the natural forces of a meteorological character is mainly the business of technical and rationalized agriculture; and if it be sufficiently